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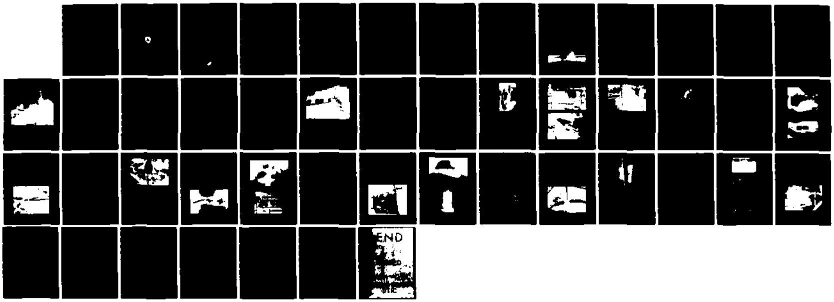

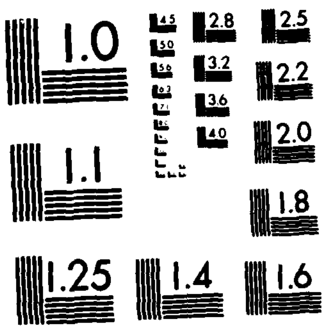

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HAZARDOUS CHEMICAL DISCHARGE PREVENTION AND REDUCTION

Richard T. Walker

U.S. Coast Guard Research and Development Center
Avery Point Groton, Connecticut 06340

MAY 1984

FINAL REPORT

PREPARED FOR
U. S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON D.C. 20593

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16. Abstract

This is the final report on the Coast Guard's Hazardous Chemical Discharge Prevention and Reduction Project. The objective of this project was to investigate and develop improved techniques and hardware to prevent the discharge of hazardous chemicals from an endangered marine vessel, and to stop or reduce the discharge from a marine transport container which is already leaking. The end products of this research and development project are passed on to the Coast Guard National Strike Force and Captain of the Port Offices for improved hazardous chemical spill response.

This is a summary report documenting a number of research project elements. The major topics of investigation include background research, hazardous chemical pumping systems, hazardous chemical emergency containers, hull rupture plugging devices and damage inspection and hardware delivery systems.

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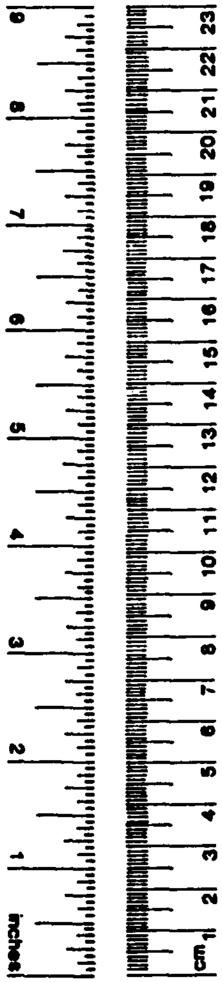
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

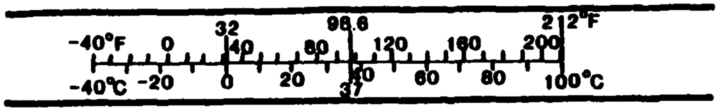
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 OBJECTIVE

The Hazardous Chemical Discharge Prevention and Reduction Project is one of six projects in the Coast Guard's overall program of Hazardous Chemical Discharge Amelioration. This program is aimed at investigating and developing equipment and methods for responding to discharges of hazardous chemicals within U.S. waters. The end users of these products will be Coast Guard pollution response personnel such as the National Strike Force, comprised of the Atlantic, Gulf, and Pacific Strike Teams, and the Captains of the Port (COTPs). Specifically, the object of the Discharge Prevention and Reduction Project is the investigation and development of equipment and methods to prevent the discharge of hazardous chemicals from an endangered marine vessel, and to stop or reduce the discharge from a marine transport container which is already leaking.

2.0 BACKGROUND

Hazardous chemicals have become an essential and inevitable ingredient in our modern industrialized society. However, there is an inherent risk in the production, transfer, and transportation of such chemicals. This risk lies in the potential damage to the health and welfare of the general public, to property, and to the environment due to accidental discharge of hazardous chemicals. Despite an abundance of rules, regulations, and preventive measures oil and hazardous chemical spills continue to occur. The ARGO MERCHANT spill shown in Figure 1 was one such disaster. The data in Table 1 (reference 36) demonstrate the magnitude of the problem.

Figure 1. ARGO MERCHANT Disaster. This grounding incident resulted in the spillage of 7.5 million gallons of #6 crude oil.

Table 1. Reported Spills of Oil, Hazardous Chemicals and Other Substances

(Gallons)

YEAR	OIL		HAZARDOUS		OTHER		TOTAL	
	#	QUANTITY	#	QUANTITY	#	QUANTITY	#	QUANTITY
1974	11,902	16,709,911	220	908,840	2,310	1,802,886	14,432	19,421,637
1975	10,868	21,724,215	239	462,420	1,674	56,385	12,781	22,243,020
1976	11,700	24,352,135	299	2,135,006	1,931	10,120,938	13,930	36,608,079
1977	12,605	9,979,381	289	1,433,291	2,436	835,046	15,330	11,247,718
1978	11,950	14,343,396	261	2,163,846	2,284	1,049,530	14,495	17,557,372
1979	10,990	10,500,344	239	433,540	1,905	2,727,444	13,134	13,661,328
1980	9,194	10,171,050	149	4,588,943	1,812	333,132	11,155	15,093,125
1981	8,820	17,800,453	93	1,050,662	1,651	922,049	10,564	19,773,164
1982*	6,752	15,460,842	242	502,312	1,072	3,667,947	8,066	19,631,101

*Denotes preliminary figures

By virtue of the Federal Water Pollution Control Act Amendments of 1972 (sub-section 311 (c)), the Magnuson Act (50 U.S.C. 191), and 14 U.S.C. 88, the Federal government has provided the Coast Guard with sufficient statutory authority to respond to any hazardous chemical discharge within the waters of the United States.

In order to develop the necessary response capability the Coast Guard Office of Operations developed a Tentative Operating Requirement (TOR) in 1969 calling for the development of capability to respond to non-petroleum spills which stated:

> "For various reasons the initial thrust of the POL (pollution) program and associated research and development has been directed toward development of an oil spill response capability. Considering the increasing quantities and type of hazardous materials handled in marine transport and the projected completion of the bulk of the oil spill response techniques, it is appropriate to place greater emphasis on other aspects of the program. Initial development of response capability for non-petroleum spills is, therefore, envisioned as a major POL program R&D initiative for FY72."

Subsequent reorganization within the Coast Guard made the Office of Marine Environment and Systems the program manager. The project was administered by the Office of Research and Development. From 1969 to 1972 the majority of Coast Guard R&D efforts in the pollution field were directed toward petroleum and sewage products. The most significant hazardous chemical effort during this time was the development of the Chemical Hazardous Response Information System (CHRIS) (references 16, 31). In 1973 a second hazardous chemical project was initiated. This project was directed toward obtaining a better understanding of the nature and scope of the problem.

In July 1974 a new program area was established to encompass and expand on the original research and development efforts directed by the 1969 TOR. Since 1974 various changes have occurred in the scope, direction and organization of this program area. The overall program of Hazardous Chemical

Discharge Amelioration was established and divided into the following specific project areas:

1. Discharge Prevention and Reduction
2. Containment, Treatment and Recovery
3. Disposal
4. Detection, Identification, Quantification
5. Personnel Protection
6. Hazard Assessment

These projects are designed to address all the critical aspects of a response capability for hazardous chemical spills in the marine environment. Discharge prevention and reduction efforts represent the first line of defense against a hazardous chemical spill. Successful discharge prevention or reduction would in turn reduce the requirements for containment and recovery operations. If the chemical cargo remained uncontaminated, this would also minimize the disposal requirements which typically follow a spill cleanup operation. When the discharge prevention and reduction efforts are not totally successful, the Containment, Treatment, and Recovery Project will provide the means for protecting the environment and minimizing the hazard associated with a chemical spill. The Detection, Identification and Quantification Project will enable response personnel to assess the level of environmental damage and long-term effects of the spill on marine usage and resources. The Personnel Protection Project will develop protective clothing and safety equipment for the Coast Guard's response personnel. The Hazard Assessment Project includes the development of the Hazard Assessment Computer System (HACS) (reference 5) designed to simulate a hazardous chemical spill situation in order to facilitate a proper response and determine the extent of a hazardous area surrounding a spill location.

As a result of the preliminary investigations it was determined that the research, development, testing and evaluation efforts in the Discharge Prevention and Reduction Project were within the scope of capabilities resident at the Coast Guard Research and Development Center in Groton, Connecticut. The project was assigned to the R&D Center in 1975. During 1976 a Proposed Technical Approach (PTA) was developed at the R&D Center and forwarded to the program manager in March of 1977. A presentation including the findings from a background study conducted under the early project efforts and recommendations for future work was made in April 1977. The PTA was approved and the Specific Operational Requirements (SOR) were forwarded to the R&D Center in August 1977 directing the Center to perform the work outlined in the PTA.

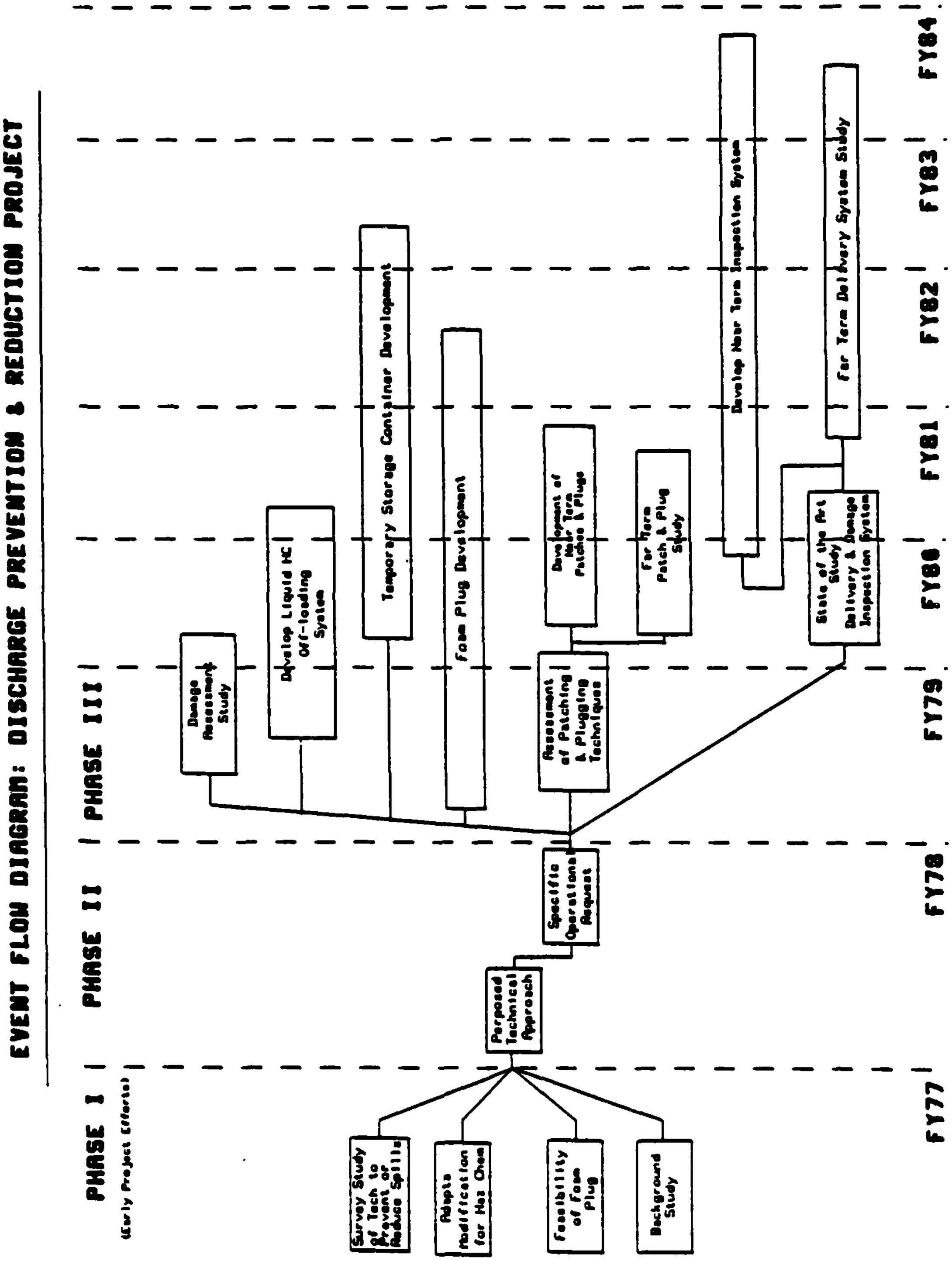
3.0 TECHNICAL APPROACH

The general approach for the Discharge Prevention and Reduction Project was divided into three main phases (Figure 2).

Phase I - Background Research (Early Project Efforts)
Phase II - Problem Definition
Phase III - Hardware Development

The application of this approach to the project is described in the following sections.

Figure 2
Event Flow Diagram



3.1 Phase I - Background Research

Research conducted during this phase resulted in a better understanding of the nature and scope of the problem and the state-of-the-art of spill prevention and reduction methods and equipment. Background research conducted during early project efforts resulted in three preliminary studies as follows:

- "Survey Study to Select a Limited Number of Hazardous Materials to Define Amelioration Requirements," (reference 9).
- "Hazardous Chemical Selection for Further R&D," (reference 34).
- "Influence of Environmental Factors on Selected Amelioration Techniques for Discharges of Hazardous Chemicals," (reference 35).

The basic technical approach applied to this task was to identify existing techniques as well as concepts for new techniques. Once identified, the feasibility of each technique or concept was assessed in light of the project goals. During this phase, three contractual efforts and one in-house effort were completed as follows:

"SURVEY STUDY OF TECHNIQUES TO PREVENT OR REDUCE DISCHARGES OF HAZARDOUS CHEMICALS," (reference 6). The purpose of this study was to survey the state-of-the-art of patching and plugging devices, identify those techniques which appear to be most promising, and to outline development plans for these items.

"AIR DEPLOYABLE ANTI-POLLUTION TRANSFER SYSTEM (ADAPTS) HAZARDOUS CHEMICAL STUDY," (reference 30). The purpose of this study was to determine the feasibility of using the Coast Guard's existing ADAPTS pump to off-load other hazardous chemicals. Two modifications have been made to the ADAPTS pump which will allow some chemicals to be pumped.

"QUICK HARDENING FOAM PLUG," (reference 25). This effort was co-sponsored by USCG and EPA to develop a quick-hardening foam plug for use primarily for land-related accidents and to identify modifications to permit a wider range of applications. This appeared to be a very attractive technique employing two-part polyurethane foam. Preliminary investigations, however, highlighted some potential problems with respect to obtaining equal part mixing, maintaining adequate temperatures for foam agent reaction, and foam curing features, especially in colder environments and in use underwater. Subsequent efforts were centered about a system using a single part polystyrene foam which appeared to have several advantages over its predecessor.

"VESSEL DAMAGE BACKGROUND STUDY." This study was done to collect data on vessel hull damage, frequency and type of marine pollution incidents. One such incident involved the Liberian tankship MT AEOLUS. This vessel struck an underwater obstruction while swinging at anchor in an established anchorage near the entrance to New York Harbor. The vessel suffered two punctures which are shown in Figure 3.

Figure 3. Hull damage sustained by MT AEOLUS

Additional technical information on the state-of-the-art of temporary containment systems, portable pumping systems and emergency hull damage repair techniques was collected. The results were presented in Appendix E of the Proposed Technical Approach (see also references 8, 21, 22, 38).

For the purposes of this project the following definitions were established during Phase I.

- Hazardous Substances - Any substance designated pursuant to subsection 311(b)(2) of the Federal Water Pollution Control Act; i.e., those elements and compounds designated as hazardous substances by the Environmental Protection Agency.

- Hazardous Materials - Other chemicals, dangerous articles or commodities regulated by the U.S. Coast Guard by such laws as the Tank Vessel Act and the Dangerous Cargo Act.

- Hazardous Chemicals - A generic term encompassing all of the above and any other hazardous chemicals not included in the other two categories.

The chemicals of concern are listed in the Chemical Hazardous Response Information System (CHRIS) (reference 3). This list has been growing steadily over the duration of the project, and now contains approximately 1106 chemicals.

3.2 Phase II - Problem Definition

As a result of the background research conducted during Phase I, and earlier project efforts, the R&D Center composed the Proposed Technical Approach (PTA). This document provided the information needed to decide on the specific course of action for Phase III: Hardware Development. Coast Guard Headquarters' decision on the project direction was contained in the Specific Operational Requirements (SOR) document which was forwarded to the R&D Center in August 1977.

Specifically, the SOR accepted the technical alternative which would provide the Coast Guard with an interim capability to off-load one-half of the pumpable chemicals with the modified ADAPTS prime mover at an acceptable pumping rate; provide temporary storage for those 500 chemicals; develop patches and plugs that will be 90% compatible with the CHRIS chemicals and to be sized for about 50-60% of the predicted damage sustained by marine chemical containers; and provide a safe means of applying these techniques by either removing the response personnel from the task or providing them with a means of protection from the hazardous environment.

A Technical Development Plan was composed by the R&D Center and sent to Coast Guard Headquarters in January 1980. This document updated the project direction and basically reaffirmed the hardware development technical approach as outlined above.

3.3 Phase III - Hardware Development

Work within this phase represents the majority of effort in the project, and followed the recommended alternative for hardware development selected from the PTA. This approach consisted of various selected low risk, near-term development efforts which were designed to provide an interim response capability during the development of selected, more effective, long-term programs. Selection of these tasks was based on the potential effectiveness of the technique, chemical compatibility, support requirements for delivery and application, development risks, and development costs. By conducting the near and far-term developments tasks in parallel, a limited

response capability was provided in a short period of time, followed by a more complete development of a full response capability in a longer time frame.

The near-term efforts were directed at modifications of off-the-shelf and prototype methods and equipment followed by field test/evaluation and operational demonstrations. At this point, hardware items of sufficient merit were handed off to the Support and Program Managers who in turn distributed them to the operational units to provide an interim response capability.

The far-term development tasks involved evaluation of selected concepts and techniques, which led to the generation of system specifications, scale models and hardware prototypes, field test/evaluation, and finally operational demonstrations. Subsystems for equipment delivery and deployment were developed concurrently with the major hardware components. Requirements for equipment storage and maintenance, and personnel training were outlined during the final phase of development. Once the outputs were handed over to the Support and Program Managers, system management and support were provided as needed.

The technical approach to Phase III outlined above is a general description of the efforts conducted in a wide range of research areas. These efforts are best described in more detail on a work unit level. The Work Breakdown Structure shown in Figure 4 outlines all the work units in the original project format. In the following sections each work unit is discussed individually, and the task objectives and major accomplishments are outlined.

4.0 PROJECT ELEMENT REVIEW

Project Element 4151.1 - Project Management

This element provided for overall project management and included project planning, systems and financial management, project appraisal (decision/risk assessment) and travel for project coordination with the Coast Guard Headquarters Offices of Research and Development and Marine Environment Systems. This element provided for a smooth transfer of the early project efforts from Headquarters to the R&D Center. The element contained one work unit.

Work Unit 4151.1.1 - Project Planning and Control

This work unit implemented the technical approach discussed above and provided overall project management, planning and control. Under this work unit a Technical Development Plan was composed and sent to Headquarters in January 1980 updating the project status and direction, and outlining the remaining hardware development tasks.

Project Element 4151.2 - Problem Definition

Under this element the R&D Center developed the Proposed Technical Approach (PTA), which was the first major planning document generated after the project was transferred to the R&D Center. The PTA assimilated the early

Figure 4
Work Breakdown Structure

WORK BREAKDOWN STRUCTURE

- HAZARDOUS CHEMICALS DISCHARGE PREVENTION AND REDUCTION
  744151
  - Project Management and System Integration
    Project Element 4151.1
    - Project Planning and Control
      Work Unit 4151.1.1
  - Project Definition
    Project Element 4151.2 — PHASE II
  - Hardware Development
    Project Element 4151.3 — PHASE III
    - Damage/Accident Assessment
      Work Unit 4151.3.1
      - Damage Assessment Study
        Sub Work Unit 4151.3.1.1
      - On-Scene Damage Assessment
        Sub Work Unit 4151.3.1.2
    - Chemical Transportation Data Base
      Work Unit 4151.3.2
    - Offloading System
      Work Unit 4151.3.3
      - CHRIS List Pumpability
        Sub Work Unit 4151.3.3.1
      - Pumping System
        Sub Work Unit 4151.3.3.2
      - Vapor Reduction Device
        Sub Work Unit 4151.3.3.2.1
      - Rigid Storage Container Development
        Sub Work Unit 4151.3.3.3.1
      - Portable Storage Container Development
        Sub Work Unit 4151.3.3.3.2
    - Patch and Plug Development
      Work Unit 4151.3.4
      - Foam Plug Development
        Sub Work Unit 4151.3.4.1
      - S.O.A. Study on Patching and Plugging Systems
        Sub Work Unit 4151.3.4.2.1
      - Near-Term Plugging System
        Sub Work Unit 4151.3.4.2.2
      - Far-Term Plugging System
        Sub Work Unit 4151.3.4.2.3
    - Delivery and Damage Inspection Systems
      Work Unit 4151.3.5
      - State-Of-The-Art Delivery and Damage Inspection Systems
        Sub Work Unit 4151.3.5.1
      - Near-Term Inspection System Development
        Sub Work Unit 4151.3.5.2
      - Far-Term Inspection System Development
        Sub Work Unit 4151.3.5.3

project efforts, reestablished the project goals, and proposed the hardware development alternatives. In support of the Problem Definition Element, the PTA included the following research efforts as appendices:

Appendix A - Study of Marine Bulk Shipments

Appendix B - Strike Force Chemical Response Capabilities

Appendix C - Details of Patching, Plugging and Off-Loading Concepts and Techniques

Appendix D - Selected Photographs of Representative Ship Damage

Appendix E - Vessel Damage Studies

Appendix F - Manned and Unmanned Submersibles

Appendix G - Atlantic Strike Team Equipment List

Project Element 4151.3 - Hardware Development

This project element was the primary work package within the project and was Phase III of the technical approach outlined above. It included studies leading to the development of new concepts as well as detailed system and hardware requirements for use in hardware development. The element also included the hardware development efforts, subsequent engineering, and operational test and evaluation phases. The element consisted of five work units and fourteen individual sub-work units which are outlined below.

Work Unit 4151.3.1 - Damage Assessment

Under this work unit damage information was collected to determine the requirements for developing effective discharge prevention and reduction hardware. It also contained a sub-work unit which allowed R&DC engineers to be on scene on a case basis in tankship/barge incidents to obtain input for realistic requirements for hardware development.

Sub-Work Unit 4151.3.1.1 - Damage Assessment Study

The SOR stated that "patches and plugs will be provided that will be 90% compatible with the CHRIS chemicals and be sized for about 50-60% of the predicted damage sustained by marine chemical containers." Since this was a premise for establishing the design requirements for the patches and plugs, a comprehensive study on hull damage resulting from collisions and groundings of tank barges, tank vessels and cargo vessels was conducted. Incidents such as the collision between the freighters SS TRANSHAWAII and the REPUBLICA DE COLUMBIA (Figure 5) were studied for details. Results of that study updated and confirmed the data gathered during the early project efforts which were reported in Appendix E of the PTA. The data gathered at that time is summarized in the following tables:

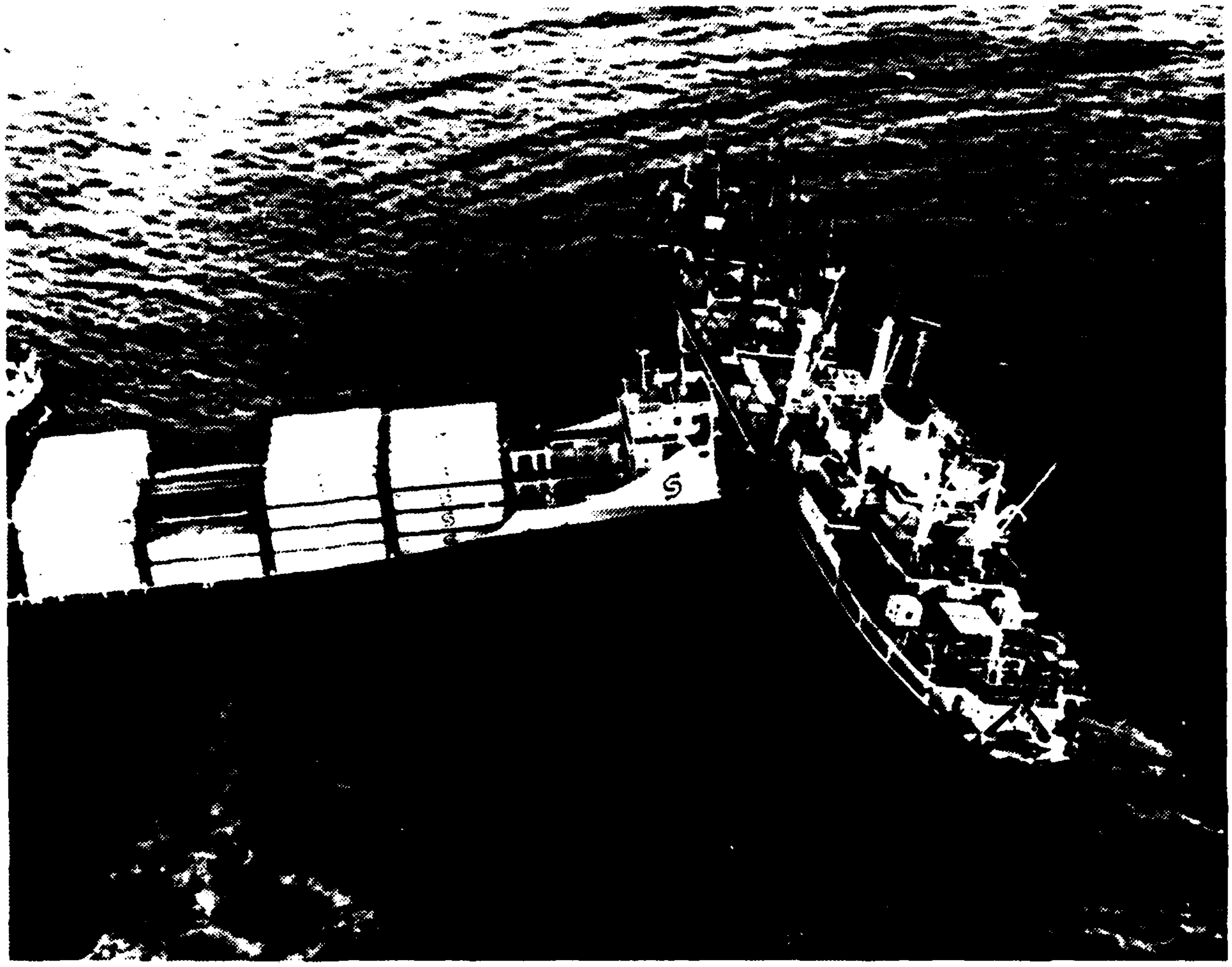


Figure 5. Collision between SS TRANSHAWAII and REPUBLICA DE COLUMBIA

TABLE 2
DAMAGE AREA - FREQUENCY OF OCCURRENCE OF HOLES IN SPECIFIED AREA INTERVALS

AREA		FREQUENCY OF HOLE OCCURRENCE PERCENT
<1	ft^2	40.8
1-2	ft^2	4.1
2-3	ft^2	3.2
3-5	ft^2	6.7
5-10	ft^2	12.9
10-100	ft^2	32.3

TABLE 3
CRACK LENGTH - FREQUENCY OF OCCURRENCE
BY SPECIFIED LENGTH INTERVALS

CRACK LENGTH	FREQUENCY OF CRACK OCCURRENCES (PERCENT)
<1 ft	50.2
1-3 ft	17.8
3-6 ft	10.2
6-10 ft	6.2
>10 ft	15.7

Reviewing the data above with respect to the SOR premise shows that 68% of the cracks are less than three feet long and 55% of the holes are less than five square feet in area. Therefore, it was concluded that these damage sizes would provide the minimum requirements for development of patching and plugging devices, and satisfy the SOR.

The report also concluded that collision or grounding damage size was proportional to vessel speed and vessel size (displacement). In a given situation, with these two parameters constant, damage size was a function of vessel design and material condition at the time of the accident. While the trend for increasing size of vessels carrying bulk liquid petroleum products was noted, it was also pointed out that the majority of U.S. marine chemical trade involves tank barges and chemical tankships which are significantly smaller in size than the large petroleum carriers.

The final report for this effort also included a state-of-the-art study of patching and plugging systems which will be discussed separately under the appropriate sub-work unit. This work unit was completed with the final report "Survey Study on Damage Assessment and State-of-the-Art of Patching and Plugging Systems" (reference 1) in February 1979.

Sub-Work Unit 4151.3.1.2 - R&D Center On-Scene Damage Assessment

This unit allowed R&D Center observers to attend the scene of marine accidents on a case basis. It was intended to provide a means of obtaining realistic input to hardware system requirements, however a limited number of incidents were actually visited over the course of the project. There were no formal reporting requirements for this task.

The unit also provided for deployment of the Remote Damage Inspection System (RDIS) on a case basis as needed. The only request for assistance during the project came from CGC REDWOOD. RDIS was successfully used to determine the source of a hydraulic fluid leak from the controllable pitch propeller mechanism. The RDIS is discussed in detail under the respective work unit.

Work Unit 4151.3.2 - Chemical Transportation Data Base

The objective of this work unit was to develop a data base on the

marine transportation of liquid bulk chemicals for use as background information in other areas of the project. A contracted effort was planned in FY79 to develop a comprehensive data base on volumes of individual liquid bulk chemicals shipped in the marine mode, methods of shipment (tank barge, tanker, etc.), tank lining materials, etc. However, this work unit was eventually cancelled, and the budgeted funds were re-allocated to a higher pay-off area within the project.

Work Unit 4151.3.3 - Offloading Systems

The objective of this work unit was to develop the appropriate hardware to increase the Coast Guard's ability to safely off-load and temporarily store hazardous chemicals from an endangered vessel. The effort involved modification and evaluation of existing hardware as well as development of new hardware items from the concept stage through engineering development and final fabrication. It was comprised of the five sub-work units which are discussed below.

Sub-Work Unit 4151.3.3.1 - CHRIS List Pumpability

The purpose of this sub-work unit was to update and extend an early project effort by Seaward International (reference 30) which investigated the use of the Air Deliverble Antipollution Transfer System (ADAPTS) for offloading hazardous chemicals. Seaward studied 266 hazardous chemicals and their compatibility with the ADAPTS. The study concluded that while 19% of those chemicals could be pumped by ADAPTS original design, the inclusion of a pump shaft seal would raise that number to 48%. Major modifications could be made which would allow ADAPTS to pump 87% of the chemicals considered.

The updated study identified 175 bulk liquid chemicals from the CHRIS list that were not considered by Seaward. Thirty of these chemicals were selected and studied to determine whether they could be pumped by an ADAPTS pump modified in accordance with Seaward's recommendations or by an all stainless steel pump. The all stainless steel pump used as an alternative in this study was the Norwegian manufactured FRAMO TK-4. The chemicals were then tabulated according to which pumping system was suitable for transfer operations. This study was completed and forwarded to Coast Guard Headquarters as an unpublished report (reference 32) in July 1978.

Sub-Work Unit 4151.3.3.2 - Pumping System

The objective of this sub-work unit was to complete the test and evaluation of various pumping systems in order to provide sufficient information for the Program/Support Managers to develop a procurement specification for a lightweight hazardous chemical pumping system.

Initial tests were conducted using the FRAMO TK-4 all stainless steel pump (Figure 6) at the Naval Coastal Systems Center in June 1978. This pump normally required a 60 horsepower motor, however in order to test it with the Coast Guard's ADAPTS 40 horsepower prime mover, it was outfitted with a different hydraulic motor. The tests were intended to establish the system's performance under simulated cargo salvage conditions. The results showed that

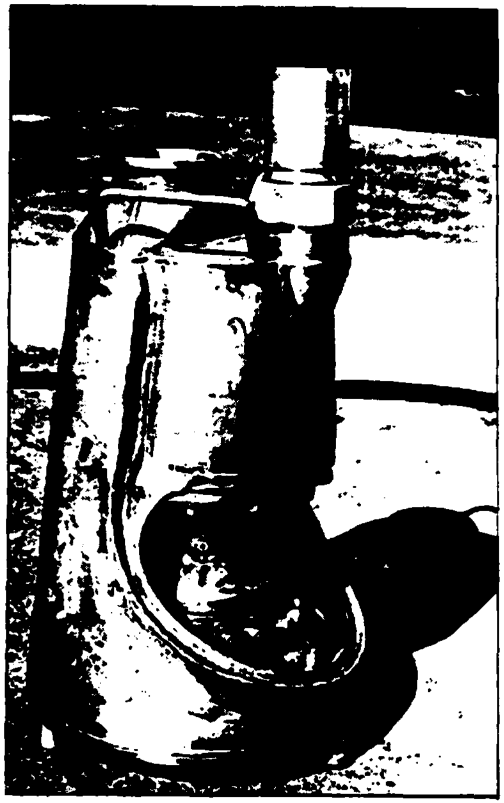


Figure 6. Framo TK-4 Stainless steel Pump

the TK-4 and ADAPTS prime mover (Figure 7) provided an acceptable pumping rate with a reasonable head for liquids with viscosities in the 1 to 110 centistoke range. This viscosity range encompasses nearly 75 percent of the CHRIS liquid chemicals shipped in bulk. Based on the test data and manufacturer's information, it was recommended that the TK-4 not be operated with heavy viscosity liquids as there was a significant drop in flow rate with liquids with viscosities over 1000 centistokes. The stainless steel discharge hose used during the tests also met the requirements for an offloading system. The test results were sent to Headquarters in an unpublished report dated July 1978 (reference 33).

Subsequent to the TK-4 tests an additional stainless steel pump, the TK-5 shown in Figure 8, became available through FRAMO. This pump had the capability for transfer of higher viscosity fluids at greater flow rate than the TK-4 with little increase in cost and weight. It was, however, designed for use with a 100 horsepower prime mover. In the meantime, independent efforts by Headquarters had resulted in the procurement of a viscous oil pumping system (VOPS) with an 80 horsepower prime mover (Figure 9). As a result of these events, the TK-5, and VOPS pumps were tested with the ADAPTS 40 horsepower and VOPS 80 horsepower prime movers.

The second set of pump tests was conducted by R&D Center and Strike Team personnel in January 1980 at the Naval Coastal Systems Center.

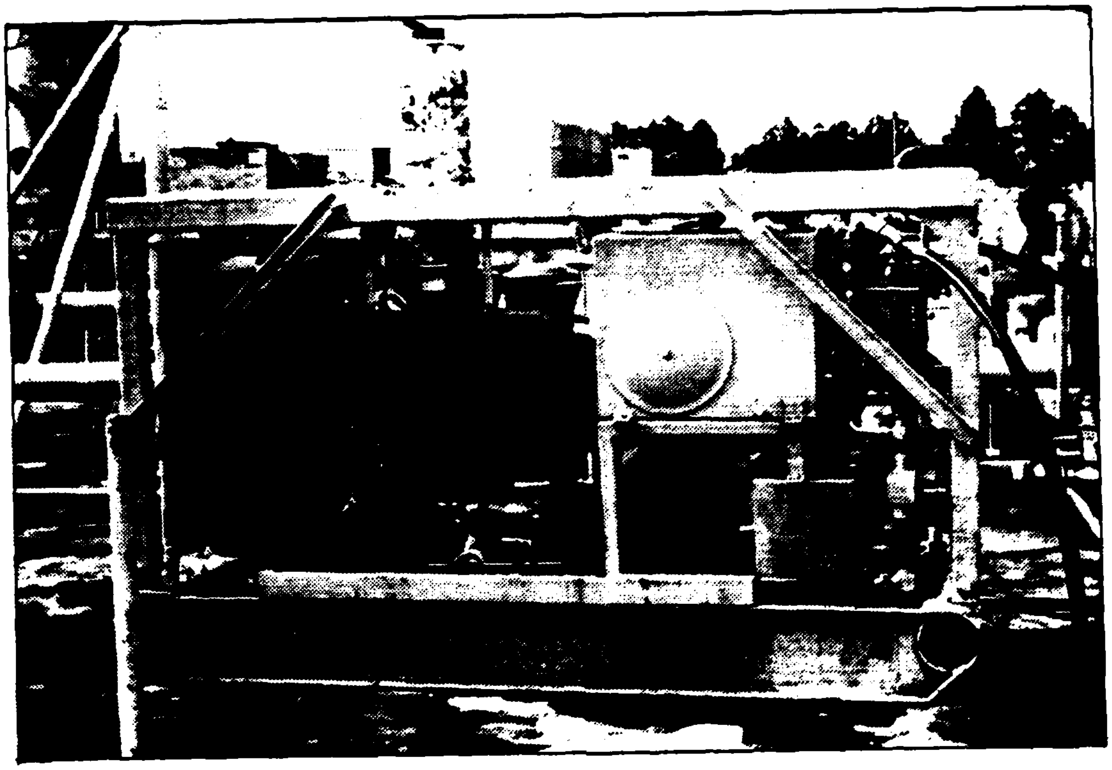


Figure 7. Adapts Prime Mover

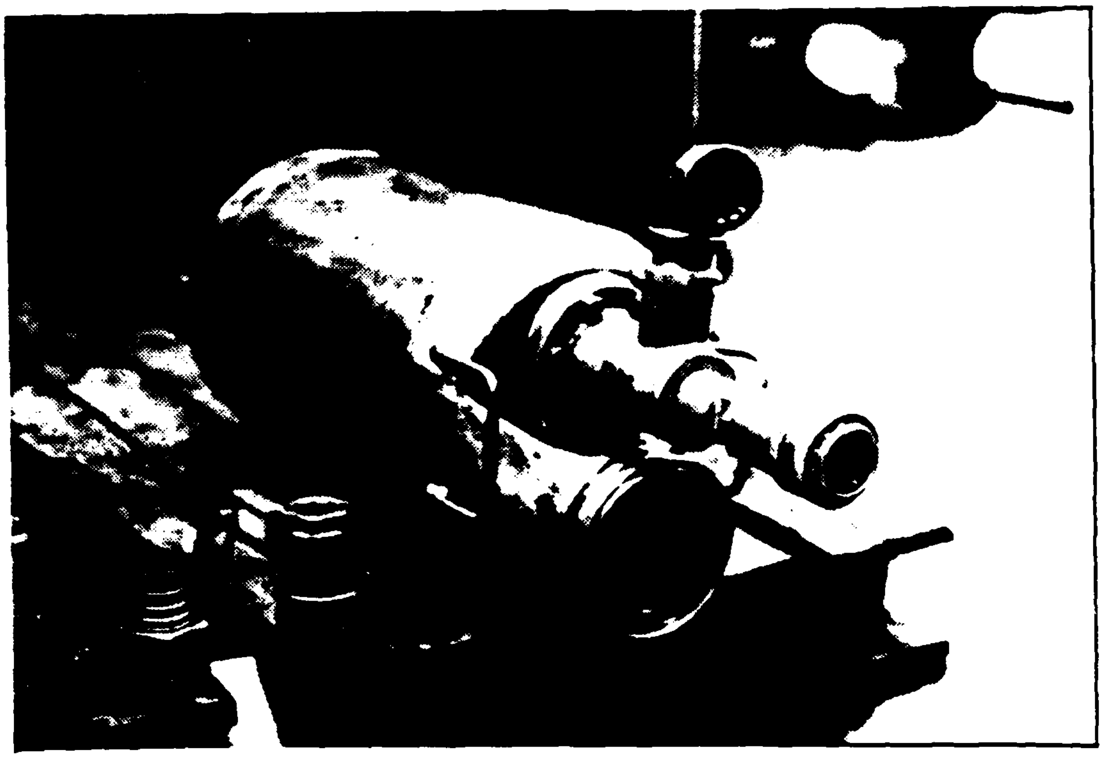


Figure 8. TK-5 Stainless Steel Pump

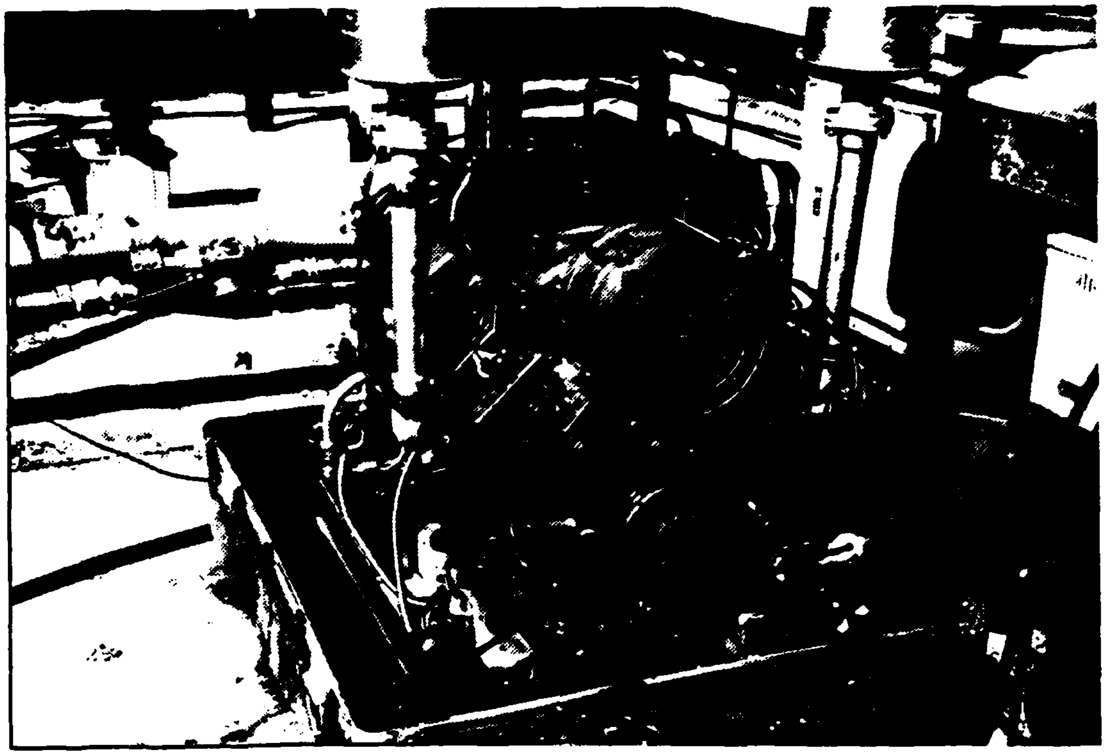


Figure 9. 80 HP VOPS Prime Mover

Water and #4 fuel oil were used as hazardous chemical simulants. Water provided a test fluid with a viscosity of 1 centistoke (cS) while #4 fuel oil had a viscosity of 110-120 cS. Viscosities were further varied using the storage tank heating and cooling capabilities at NCSC.

The tests showed the TK-5 performance was superior to the TK-4, and it worked well with the ADAPTS prime mover. Both the TK-5 and the VOPS pump performed well with the VOPS prime mover. It was found that the VOPS prime mover could operate two TK-5 pumps simultaneously.

These test results were reported in "Hazardous Chemical Pump Tests" (reference 20) in July 1980.

Sub-Work Unit 4151.3.3.2.1 - Vapor Reduction Device

The Vapor Reduction Device (VRD) was developed for use by Coast Guard Strike Teams during emergency lightering of liquid hazardous chemicals and petroleum products. The device is placed around and over deck openings which are being used for the off-loading procedures and effectively reduces toxic vapor concentrations which may be hazardous to response personnel and the integrity of their protective clothing.

A general concept drawing of the VRD is shown in Figure 10. The device consists of three main components, the top section, the skirt

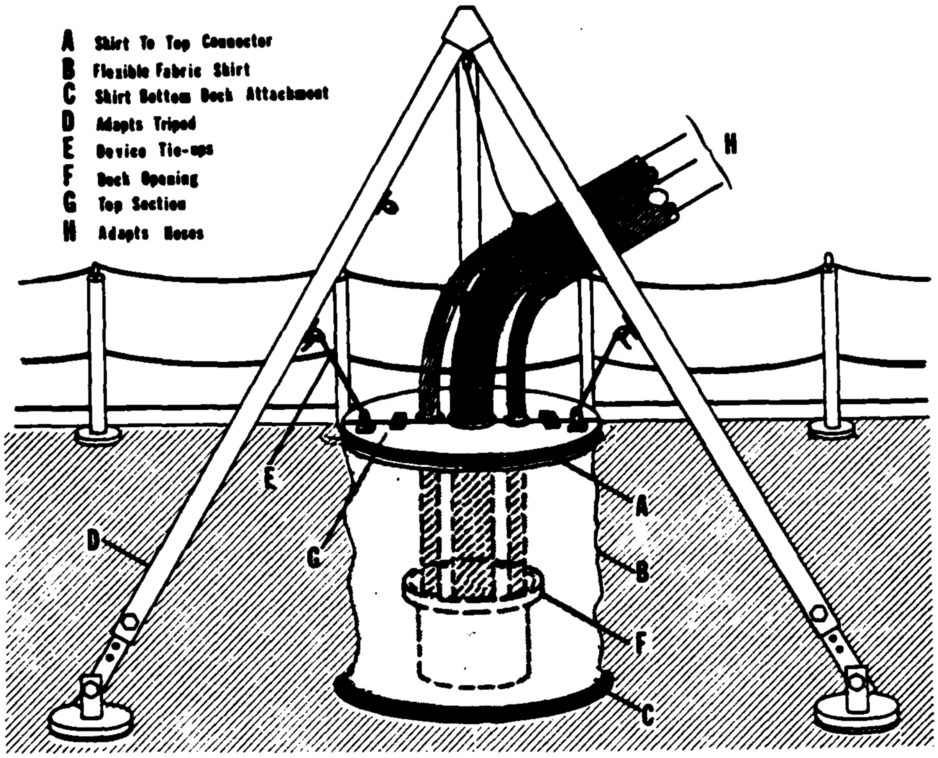


Figure 10. Vapor Reduction Device General Concept

section, and the bottom section. The top section is a slide cover top fabricated from teflon plate. It was designed to allow the ADAPTS hazardous chemical pump and hoses to be inserted or removed without removing the VRD. The skirt section which fits around the deck opening was made from viton-coated dacron and is connected to the top section by a barrel cover clamp-type closure. For production models it was recommended that a series of skirts be made using such materials as viton, butyl rubber, and neoprene. In this way virtually all liquid hazardous chemicals could be handled with no reduction in chemical resistance or seal integrity. The bottom section consists of a magnetic rubber strip which is laid on the deck around the opening. The skirt is attached to this using a velcro closure which serves to hold down the bottom of the skirt and maintain the vapor seal. The entire assembly is supported by an external tripod. The VRD was designed to fit around a variety of deck openings from a 12-1/2 inch diameter flush deck Butterworth opening to raised cargo hatches with coamings 30 inches in diameter and 48 inches high.

Tests were conducted at the R&D Center to measure the effectiveness of the VRD under simulated off-loading conditions. A mock-up of a tanker deck with tank openings was constructed over an existing empty steel frame pool for the tests. Chemical vapor was produced by evaporation of liquid heptane from a shallow tray placed just below the tank opening rim. Vapor concentrations were measured at several stations around the opening, both with and without the VRD in place. Test results showed that the VRD

significantly reduced the vapor concentration levels around the deck opening. In most cases the concentrations were reduced to within 1 part per million of the background level, which was determined to be a reasonable threshold limit target value for ensuring personnel safety. This sub-work unit was completed with a design and prototype hardware hand-off to Headquarters. The effort was documented in the final report "Hazardous Chemical Vapor Reduction Device Development" of October 1979, reference 8 (see also reference 19).

Sub-Work Unit 4151.3.3.3.1 - Rigid Storage Container Development

The objective of this task was to develop a rigid container for temporary storage of hazardous chemicals and petroleum products during spill cleanup operations. The container was to be deployed on the Coast Guard's existing Fast Surface Delivery Sled (FSD), a towable barge capable of planing speeds. For spills with a large number of patches, but in relatively small quantity, there appeared to be some logistical advantages in using a maneuverable, high speed, temporary storage system of this type. Once a request is initiated by an on-scene coordinator of a spill cleanup, this type of container could be transported to the debarkation area by C-130 aircraft or flatbed truck, and then loaded onto the FSD and towed to the spill site. The mission requirements called for the container and sled to be stable during loading and also for the ability to float the container off the sled while fully loaded. This effort was initiated to complement the ongoing portable flexible container development described in the next section.

In order to reduce development time, a standard General American Tank Corporation (GATX) 5,000 gallon container (Figure 11) was purchased and modified for this program. Preliminary stability calculations generated by a computer model were followed by scale model testing at the U.S. Naval Academy. The model test documented container/sled stability characteristics. Pitch, roll, and heave in various seaways and loading conditions were measured. The test data were used for guidance in the full-scale test program. Results indicated marginal stability for the fully loaded tank/sled combination. As a result, additional flotation modules were added to the FSD.

In June 1981 full-scale tests were conducted in Long Island Sound. These tests included static righting arm/stability tests as well as underway towing and maneuverability tests. Figure 12 shows the container/sled arrangement during the towing tests. Various loading conditions and towing directions with respect to the seaway were tested, and data was collected on the motion characteristics. Towing speeds of 12.5 knots were achieved using a 95-foot Coast Guard Patrol Boat, even with the tank fully loaded. Problems were encountered when several of the temporary flotation modules added to the FSD were knocked off by wave forces. The sled capsized during retrieval after the last towing tests and returned to the dock inverted. All equipment was salvaged and the sled and container were righted. The tests showed that the rigid container/FSD system is able to perform the task, however, Strike Team members who participated in the test had reservations on the logistical aspects and ultimate utility of the system. There was concern that the necessary modifications to the FSD would inhibit other, established functions of the sled. Although the system was workable, it was not easy to handle in

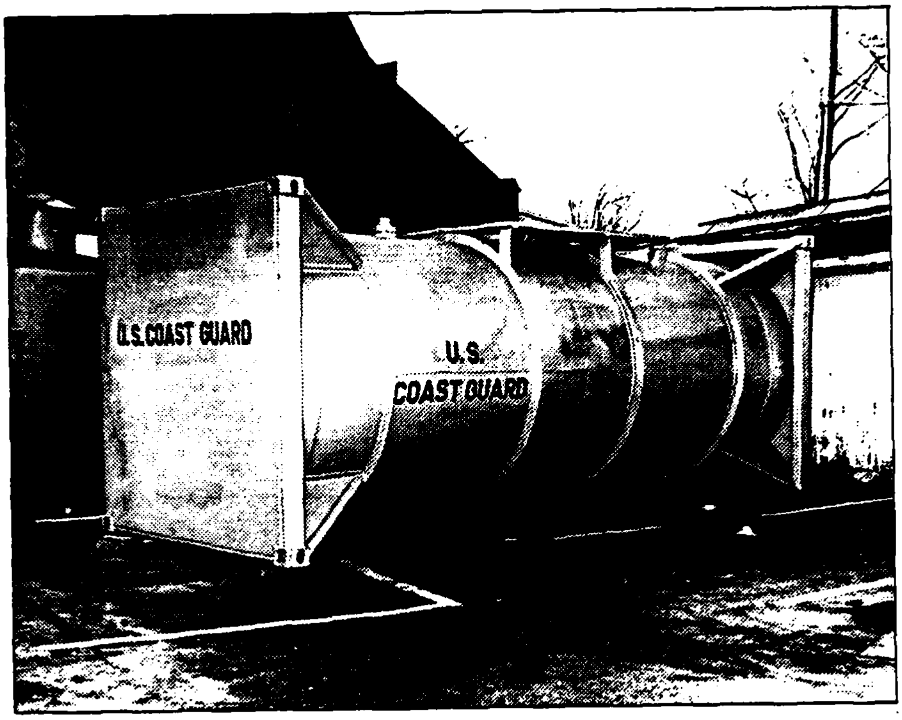


Figure 11. GATX 5000 Gallon Rigid Container

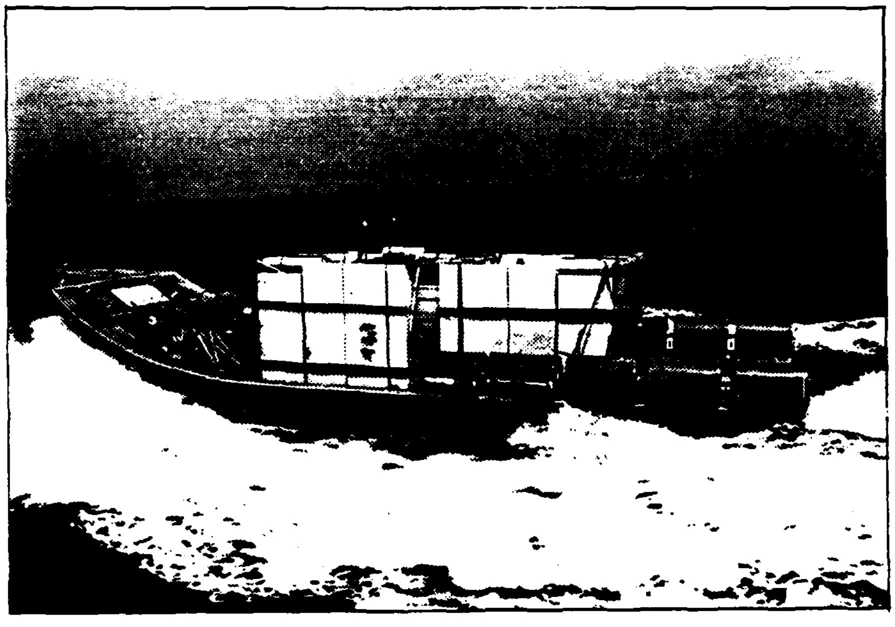


Figure 12. Rigid Container on the FSD During Field Testing

the fully loaded condition. Finally, the utility of a small rigid container for hazardous chemical spill cleanup was questionable. Such a container without a decanting device would be able to recover a quantity of pollutant significantly less than the total capacity of the container. As a result, this effort was terminated and the results were forwarded to Headquarters in an unpublished report "Test and Evaluation of the Pre-Prototype Rigid Container" (reference 29) in December 1981.

Sub-Work Unit 4151.3.3.3.2 - Portable Storage Container Development

The Coast Guard has had floating flexible rubberized containers (Dunlop's DRACONES - see Figure 13) in their offloading equipment inventory for some time. The same type of temporary storage container, with a much larger capacity than the rigid container just described, would be advantageous for offloading damaged chemical tankers and barges. Ideally, the same container would be used for both situations. However, the chemicals are often heavier than water and would not be compatible with the materials used in the standard flexible oil containers. As a result, the Coast Guard contracted Goodyear Aerospace Corporation to conduct a hazardous chemical container feasibility/concept design study to determine the feasibility of developing and using portable containers to offload hazardous chemicals at sea and to provide conceptual design alternatives.

Figure 13. DRACONES Flexible Container

An early review of the CHRIS chemicals indicated that approximately 42 percent of the chemicals could be carried in the existing oil containers. With additional flotation, 60 percent of the chemicals could be carried. To exceed this limit the container would have to be fabricated from improved materials and have the added flotation. The project goal of handling 90 percent of the CHRIS chemicals resulted in using a specific gravity of 1.9 as the design requirement. Additionally, the container was to have a volume of 25,000 gallons, towing velocity of 10 kts, a packaged weight of less than 15,000 pounds, and a loaded draft of less than 10 feet. The design requirements indicated a need to increase the fabric strength and seam strength of present containers by a factor of two. The chemical compatibility requirments also indicated a need for significant enginering development in this task. The study was completed and the results documented in the report "Hazardous Chemical Container Feasibility/Concept Design Study" (reference 4) in April 1981.

Three design approaches were suggested in the report. While each approach could theoretically meet the technical requirements, there was considerable development risk associated with the proposed follow-on effort. Two of the three design approaches involved advancing the state-of-the-art in material technology and fabrication. The third approach resulted in the heaviest final package. The hardware development and fabrication costs were projected to be fairly high, ranging from $150,000 up to $600,000 per unit in lots of ten. As a result, further work in this area was suspended.

Work Unit 4151.3.4 - Patch and Plug Development

The objective of this work unit was to study, identify, and develop patching and plugging devices and techniques to aid in preventing or reducing the discharge of chemicals into the water from damaged marine container vessels. The effort was implemented through the four sub-work units discussed below.

Sub-Work Unit 4151.3.4.1 - Foam Plug Development

Rockwell International, under joint sponsorship of the EPA and Coast Guard, conducted an effort over a number of years to develop a rapid forming plugging system for plugging leaking chemical containers. By 1976 a prototye system was developed for dealing with land based spills of hazardous chemicals. The prototype is shown in Figure 14. The PTA for this project called for further development of the leak plugging system. The prototype system used a two-part polyurethane foam which was mixed and ejected into an elastic protective membrane to form a rigid plug. The system was portable and could be operated by one man. However, the device had a significant temperature limitation. When the ambient temperature was less than 45°F the foam formation was impaired. This lower temperature limit made that particular foam formulation unsuitable for a device to be used underwater or in air in cold weather conditions. Several technical papers have reported the progress of this work since it began. See references 2, 12, 13, 14 and 15.

This sub-work unit represents a subsequent effort by the Coast Guard to develop a similar plugging device suitable for deployment by divers to plug damaged bulk carriers of hazardous chemicals in the marine environment. Investigations were directed at single component foam systems

Figure 14. Prototype Leak Plugger

which were simpler, cheaper, and operable in low ambient temperatures and pressures equivalent to 50 feet of sea water. A prototype system was developed using a single component polystyrene foam formulation which met the basic design requirements. Further work was then conducted to refine the leak plugger design, and develop a bulk loading system. The final configuration of the "foam lance" is shown in Figure 15. The stainless steel lance contains the polystyrene foam mixture in solution and under pressure between two burst disc assemblies. An externally mounted trigger fires a CO_2 cartridge to expel the foam from the lance. Figure 16 shows the applicator tip, which consists of a hardware assembly covered by a vinyl fabric bag, and mates to the lance by a Kamlock connector. To operate, the lance is inserted into the damaged area and the trigger is pulled. The expanding CO_2 gas forces the foam solution out of the lance into the applicator tip. The solution off-gases immediately and the foam lattice forms in a matter of seconds. A rigid foam plug forms in the applicator tip in less than 10 seconds. See Figure 17. The Kamlock connector can be released and the foam lance may be reused. Buoyancy packages mounted on the lance make it easy to handle and slightly positive when spent.

In order to efficiently fill the lances a bulk loading system was developed and installed at the R&D Center. The system as shown in Figure 18 had the capacity to load approximately 20 lances per mixture.

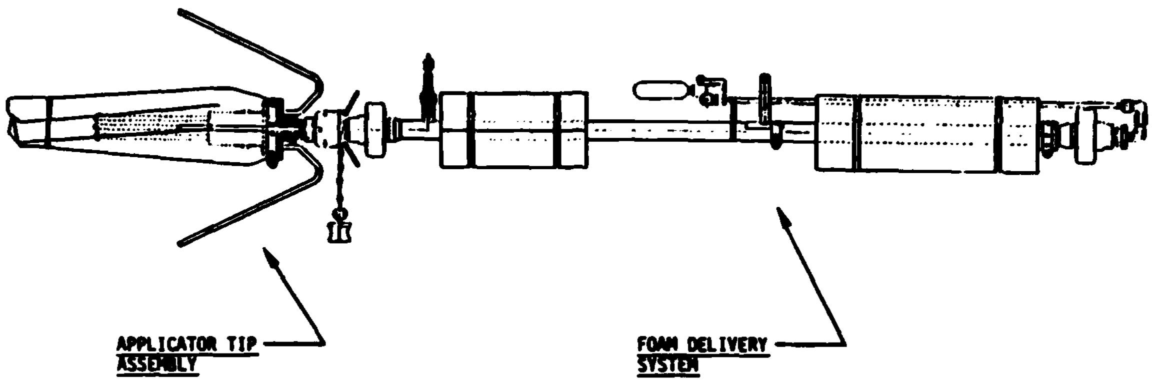


Figure 15. Foam Lance Final Configuration

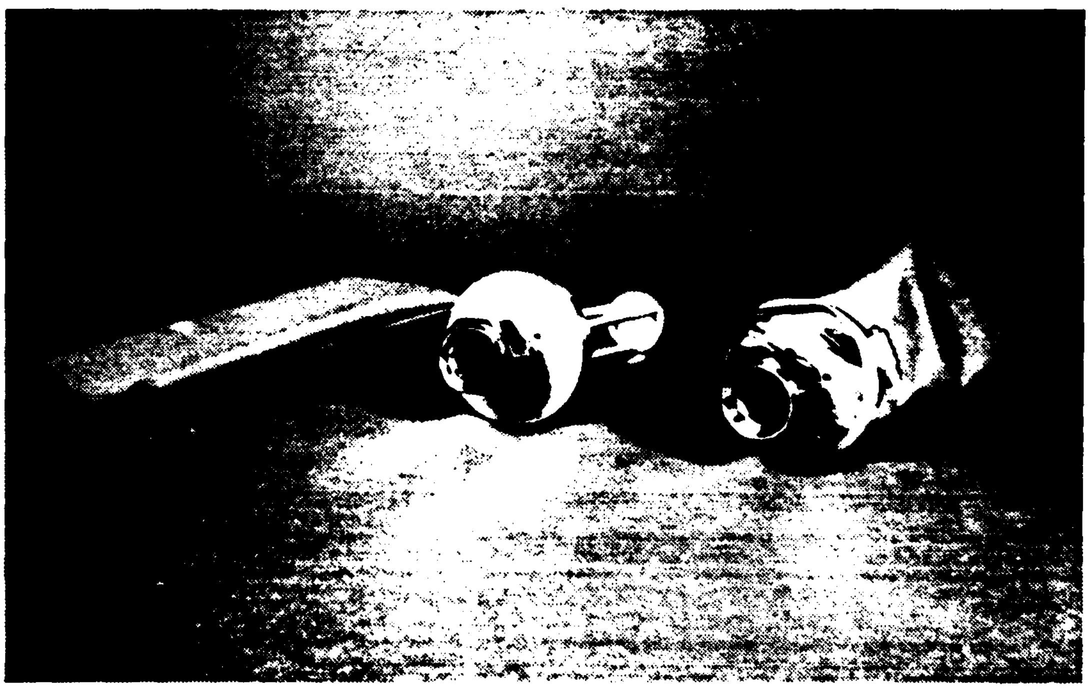


Figure 16. Foam Lance Applicator Tip

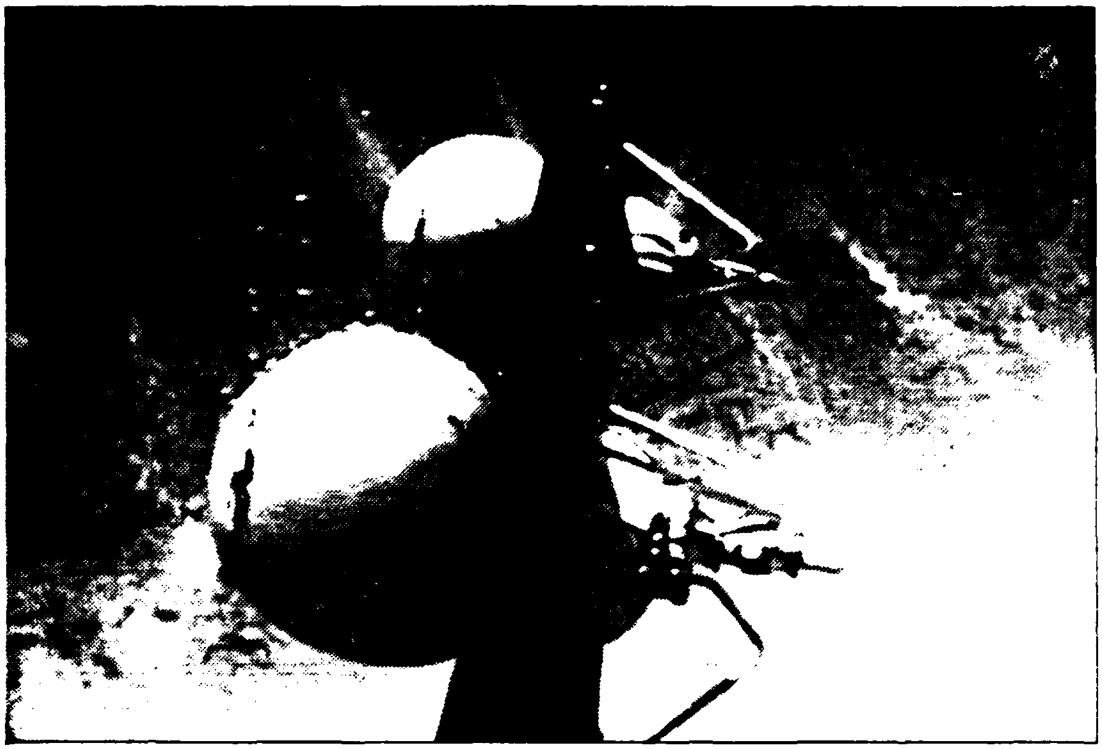


Figure 17. The Rapid Forming Foam Plug

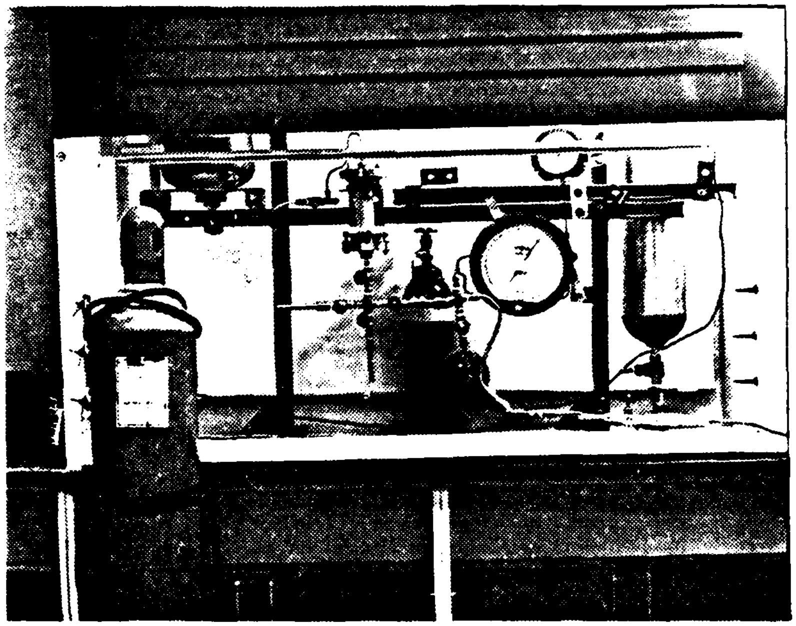


Figure 18. Bulk Loading System for Foam Lance

The foam lance has been successfully tested both in the laboratory and in the field. Laboratory tests documented plug formation in low temperature and elevated pressure environments. Underwater field tests were conducted using Strike Team divers in August 1979. At that time holes up to 8 inches in diameter were successfully plugged. Concurrent work under the Far Term Inspection System Development showed the feasibility of deploying the foam lance from a remotely operated vehicle. The final report on this effort, "Foam Plug Development" (reference 11), was completed in April 1980. In July 1980 all three Strike Teams received foam lances for operatioal evaluation while the R&D Center maintained the bulk loading station as a support function.

Sub-Work Unit 4151.3.4.2.1 - State-of-the-Art on Patching and Plugging Systems

Information on patching and plugging systems was collected during the Phase I Background Study and included as Appendix C in the Proposed Technical Approach. The intent of this sub-work unit was to review the data gathered during Phase I and to supplement this with information on any patching and plugging methods devised since the PTA was written. Once the data was collected, all concepts were evaluated from the standpont of practical application to the Coast Guard mission. Previous evaluations were more concerned with the design, engineering, and development aspects of the patching and plugging devices. During the Phase III study and evaluation, extensive field investigations and interviews were conducted to assess the device or concept in terms of its potential for solving the practical problems encountered during a hazardous chemical spill response.

Results of this study were combined with a damage assessment study. The final report "Survey Study on Damage Assessment and State-of-the-Art of Patching and Plugging Systems" (reference 1) was completed in February 1979. The study concluded that future hardware development should focus primarily on plugging devices. Plugs appeared more suitable for quick response emergency repairs for discharge prevention, while patching techniques, such as shown in Figure 19 which generally take longer to install, are more appropriate for damage control measures. The specific plugging devices which were selected for near-term development were:

1. Inflatable Plug
2. Rockwell Foam Plug
3. Evacuated Foam Plug

As a result of the conclusions and recommendations of this study the Near-Term Plugging System effort was initiated. It was also recognized that incidents involving the more corrosive and toxic chemicals preclude the use of divers as a matter of safe practice. However, the utilization of protective clothing (non-underwater), developed for Coast Guard pollution response force use, provides relatively safe working conditions for personnel operating on a stricken vessel's deck performing emergency offloading procedures. For these reasons it was concluded that a study should be conducted to determine the feasibility of performing plugging operations remotely through standard tank vessel deck openings. The conduct of such a study would guarantee that the Coast Guard has made a comprehensive evaluation of all possible methods which could be adopted for use in preventing or reducing hazardous chemical

discharges from endangered vessels. The study results would present and recommend viable systems/concepts for potential far-term development in the area of internal tank plugging (see the Far Term Plugging System work unit description).

Sub-Work Unit 4151.3.4.2.2 - Near-Term Plugging Systems

The development of the plugging devices (other than the Rockwell foam plug) identified in reference 1 was conducted under this sub-work unit. In particular, the inflatable plug consists of a hypalon coated natural rubber bag and inflation system. The bag was adapted from the commercially available "pipestoppers" and comes in a variety of sizes with expanded diameters from 6 to 108 inches. The bag is inserted into the damaged area and inflated by one of several means. Two small bags (8 and 12 inches) were modified for use with a CO_2 cartridge (see Figure 20) and a metering valve for controlled inflation. Alternately, a diver may use his own source of compressed air for inflation through the standard Schrader valves. For safety purposes and plug effectiveness the larger bags (16, 18 and 36 inches) are filled with ambient sea water. These bags were fit with a ball valve and a 1/2-inch Kamlock connector. In order to fill these bags the Self-Contained Underwater Pumping System (SCUPS) was developed. This device is totally submersible and is shown in Figure 21. The housing is constructed of 10-inch diameter PVC pipe and 3/4-inch PVC sheet material.

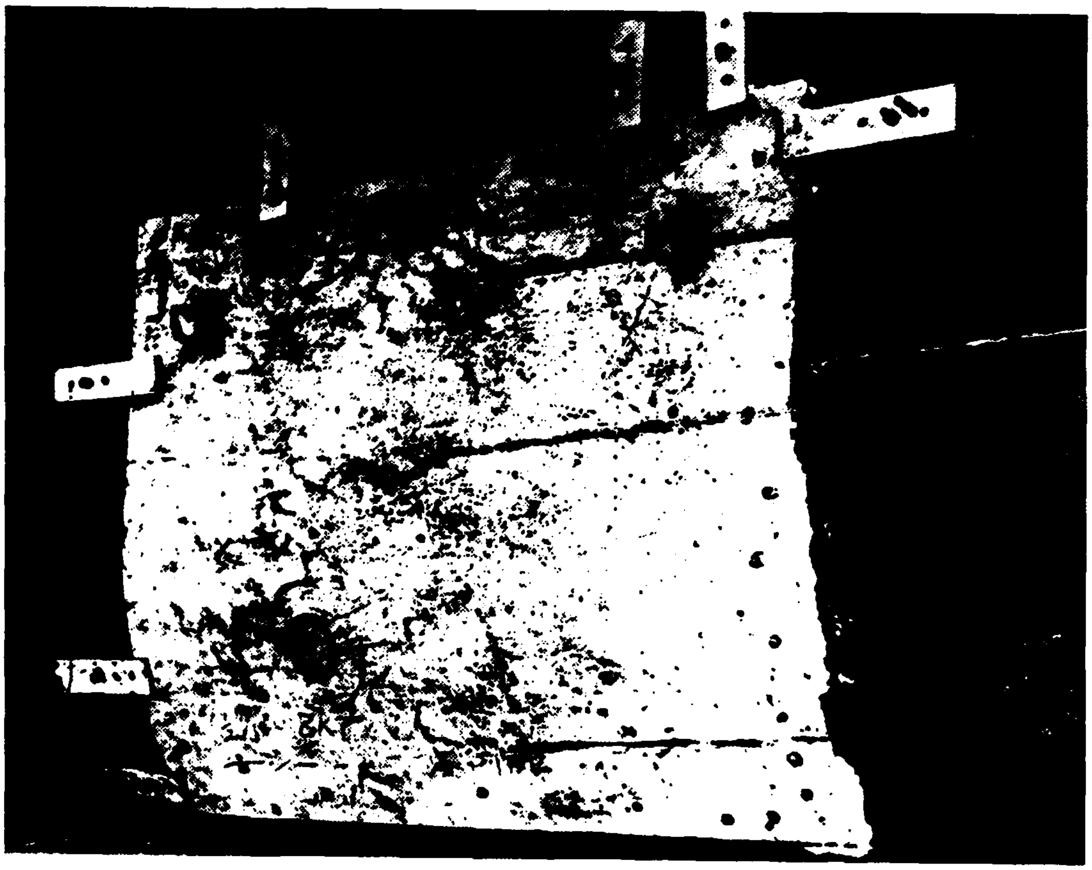


Figure 19. Typical Patching Technique

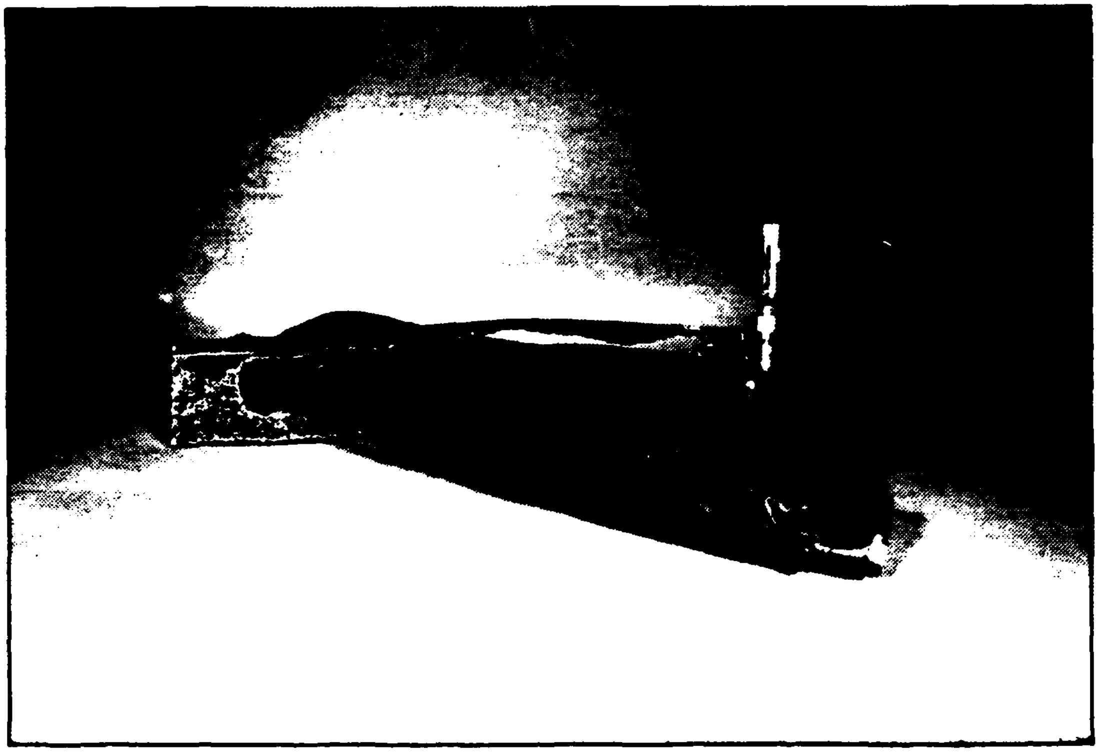


Figure 20. CO_2 Inflated Pipestopper Bag

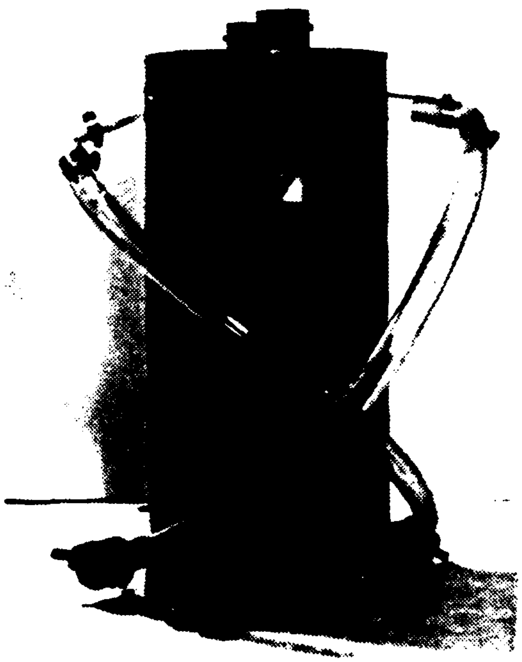


Figure 21. Self-Contained Underwater Pumping System (SCUPS)

The unit has two sections. One section, which is free-flooding, contains two standard 1750 gph submersible bilge pumps. The other section is watertight and houses a 12 volt 28 ampere-hour gel cell battery. Two 1-inch diameter tubes with Kamlock connectors provide the discharge connection to the bag. SCUPS weighs approximately 45 pounds in air and is almost neutrally buoyant in water. It is capable of delivering 3500 gph at low head.

Another plugging device developed and tested under this effort is the evacuated foam plug. The plug consists of a block of open celled polyurethane foam encased in an airtight fabric-reinforced rubber bag. A section of perforated PVC pipe runs down the center of the foam block and attaches to a 2-inch plastic thru hull fitting at one end of the bag. A 1-inch PVC ball valve is attached to the other end of the thru hull fitting and serves as the activation method. A schematic of this device is shown in Figure 22. To "arm" the system a vacuum pump is attached to the ball valve connection and energized. The vacuum causes the foam to collapse to approximately 1/8th its original size. The ball valve is then closed and the vacuum pump removed. When the plug is placed in a damaged area and the ball valve is opened, the foam returns to original size as it absorbs water. Foam plugs of 8-inch, 12-inch and 34-inch square cross section were fabricated using readily available materials with lengths of 24 inches, 30 inches and 32 inches, respectively. This plugging device benefits from its simplicity, effectiveness, ease of handling and activation, and low manufacturing costs.

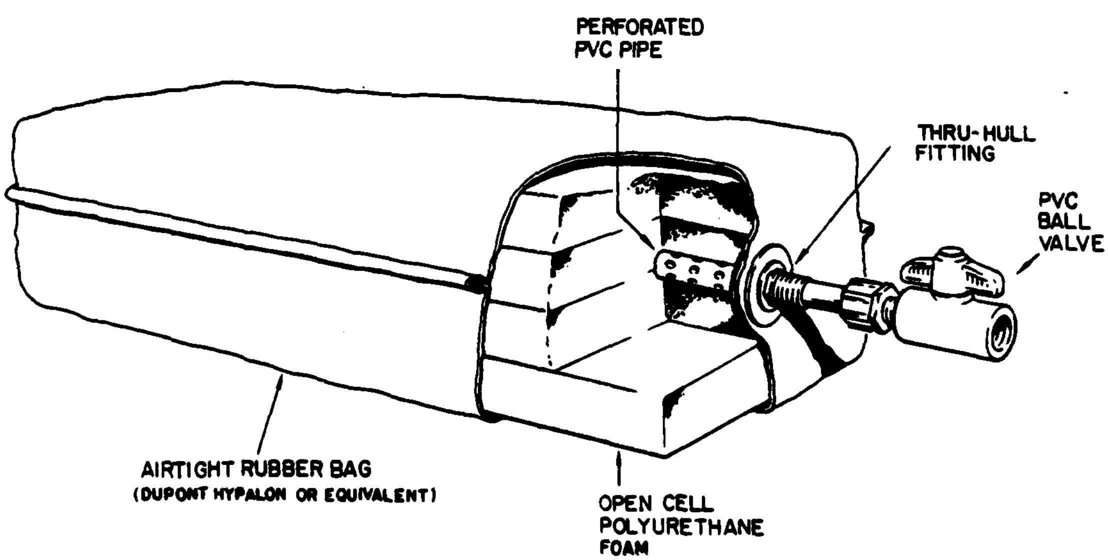


Figure 22. Schematic of Evaculated Foam Plug

The plugging devices developed under this sub-work unit, along with SCUPS and the Rockwell foam plug were all field tested with Strike Team divers in August 1979. The divers used the plugging devices singly and in various combinations to plug simulated damage target holes. See Figures 23 and 24. The participants' responses were quite favorable and the plugging devices were the subject of a hardware handoff in July 1980. This effort was documented by the final report "Vessel Damage Plugging Device Development, Test and Evaluation" which was completed in October 1979. See reference 39.

Sub-Work Unit 4151.3.4.2.3 - Far-Term Patch and Plug Development

In order to insure that all possible approaches to the patching and plugging aspect of spill prevention and reduction were pursued, a study contract was awarded in the 4th quarter of FY79 to investigate the feasibility of plugging vessel tank damage from inside the tank. ORI, Inc. conducted an extensive literature search for technology applicable to interior tank patching. Computerized data bases, professional journals, interviews with manufacturing personnel and professional society members as well as U.S. Patent Office files were used to develop a list of 31 patch/plug and 8 delivery systems with potential application to the problem. The candidate systems were subjected to a systematic and detailed evaluation and priority ranking. The evaluation was initially conducted by four panel members selected from the prime and sub contractors and the Coast Guard, working independently. Consensus of evaluations and rankings was then developed

Figure 23. 36-inch Pipestopper Bag in Simulated Damage Hole

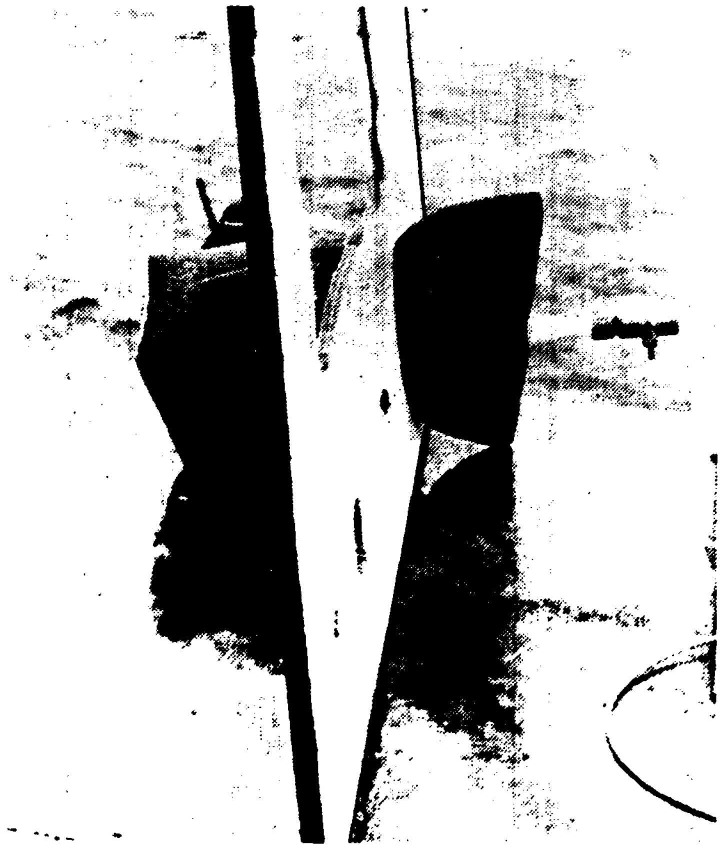


Figure 24. Evacuated Foam Plug Deployed During Field Tests

during a joint session. The study did not identify any systems uniquely designed for in-tank plugging. The majority of systems in the initial inventory were rated unsatisfactory. However three patch/plug and three delivery systems were identified as having potential application, but it was noted that they would require considerable R&D effort to develop a practical working system. Based on the results which were forwarded to Coast Guard Headquarters in the final report "Techniques for Remote-Controlled Interior Patching of Tanker Hulls" in April 1980 (reference 3), efforts in this area were terminated in favor of more conventional exterior plugging methods with significantly lower development risks.

Work Unit 4151.3.5 - Delivery and Damage Inspection Systems

The objective of this final work unit under Phase III was to develop underwater inspection systems and delivery platform systems for use by Coast Guard response forces in locating and assessing the extent of vessel hull damage, and the remote application of plugging devices. A secondary objective was to investigate the utility of these systems for use in remote sampling of spilled material. This work was split into three sub-work units as described below.

Sub-Work Unit 4151.3.5.1 - State-of-the-Art Study of Delivery and Damage Inspection Systems

This study was conducted to assess methods that might be used by the Coast Guard in accomplishing three main tasks during a hazardous chemical spill response. The specific tasks were identified as follows:

1. Damage inspection of the endangered vessel.

2. Delivery of Coast Guard hazardous chemical plugging devices (polystyrene foam plug, evacuated foam plug, and inflatable bags).

3. Delivery of a sampling device to facilitate material identification and concentration, and provide input for venting rate estimates used in the Hazard Assessment Computer System.

The mission requirements and hardware design goals were established followed by a survey of the possible deployment methods. The methods included manned systems (divers and manned submersibles) and various configurations of unmanned remotely operated vehicles (ROVs). The deployment methods were reviewed and subjected to a weighted factor evaluation. The evaluation criteria included functional utility, safety and cost. The evaluation results showed the most promising approach to satisfying the stated mission objectives was the remotely operated vehicle with some work capability. For basic inspection tasks, the simpler and typically smaller observation ROV is adequate.

An extensive review of existing ROV systems was conducted. Based on the information collected, the vehicles were ranked according to their suitability for the intended mission. The rank ordering of ROV's provided the basis for further work under the Far-Term Delivery and Damage Inspection Systems sub-work unit. The final report for this effort (reference 26) was completed in April 1980.

Sub-Work Unit 4151.3.5.2 - Near-Term Inspection System Development

The Remote Damage Inspection System (RDIS) was developed to satisfy the Coast Guard's short-term requirement for the ability to conduct remote inspection of damaged bulk carriers of hazardous chemicals. Response personnel have expressed the need for this capability because in many cases normal damage inspection techniques using divers are precluded due to the safety hazard associated with the spilled hazardous chemical. RDIS consists of an underwater TV camera system and lightweight delivery cage for deployment from the deck of the stricken vessel. Figure 25 shows an artist's concept drawing of the RDIS. The prototype system included a pan and tilt unit for the TV camera and a 35 mm underwater camera and strobe. The system was field tested from a number of vessels and the concept feasibility proven. However, the RDIS prototype was too heavy and awkward for manual deployment over the vessel's rail. As a result, the payload was streamlined and the cage redesigned to be more manageable topside. Subsequent field tests confirmed the improved handling characteristics. The ultimate cage configuration is shown in Figure 26. This effort was completed with a final report (reference 27) and design handoff in December 1983. The RDIS is currently being maintained at the R&D Center for deployment on a case basis as required.

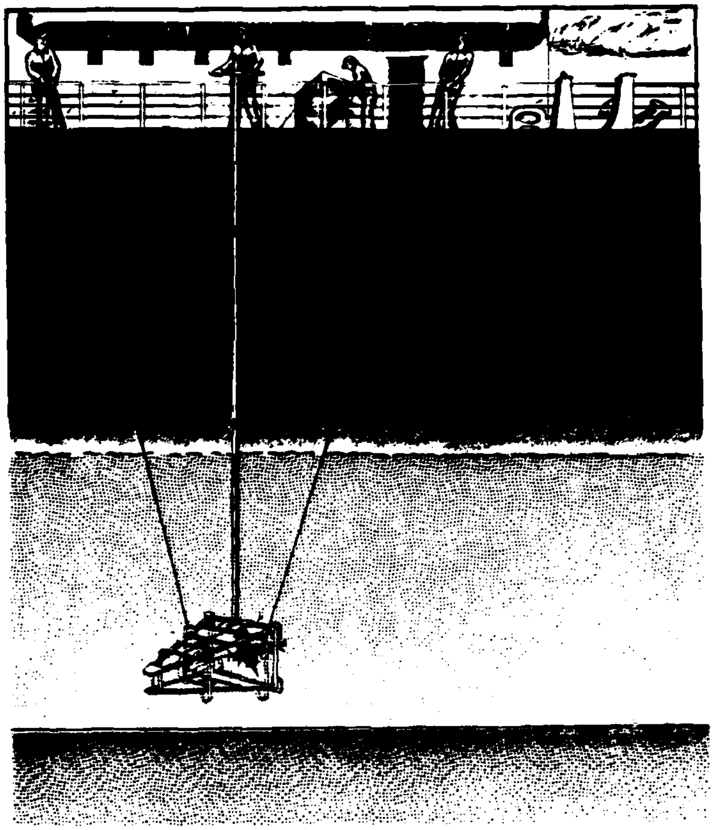


Figure 25. Artist's Concept Drawing of the Remote Damage Inspection System

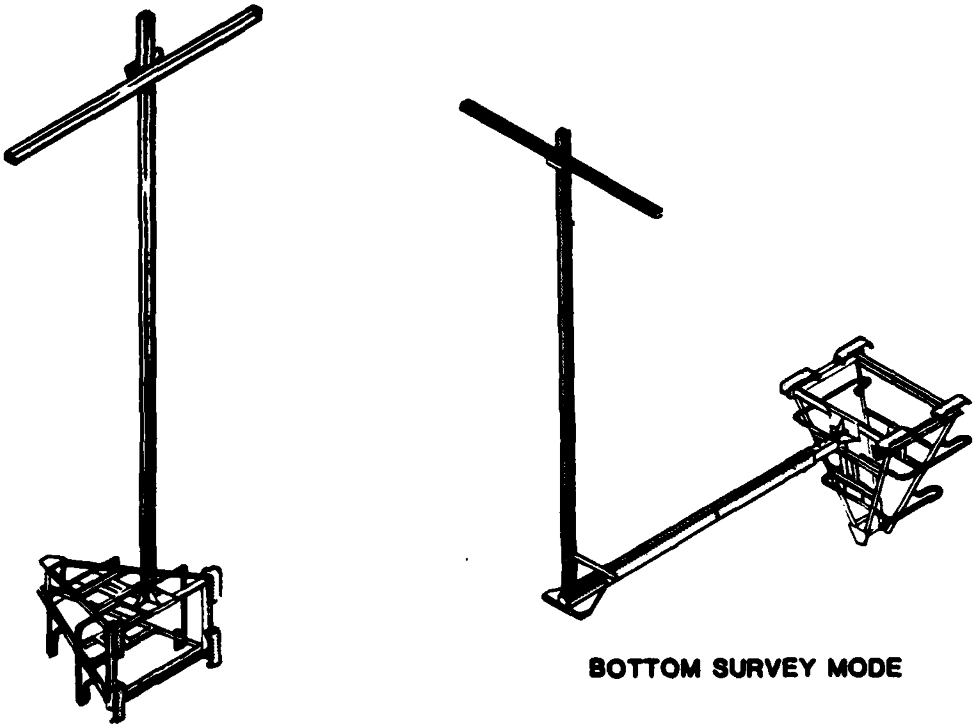


Figure 26. RDIS Cage Configuration

Sub-Work Unit 4151.3.5.3 - Far-Term Delivery and Damage Inspection System Development

The objective of this final sub-work unit was to develop a response tool capable of hardware delivery as well as remote damage inspection. This effort is a direct follow-on to the State-of-the-Art Study of Delivery and Damage Inspection Systems described earlier. That study recommended specific Remotely Operated Vehicles as candidate systems for further development as a Coast Guard hazardous chemical spill response tool. The mission requirements established during that study (remote inspection, plugging and sampling) as well as the review of ROV specifications provided the basis for selecting an ROV and conducting a field test and evaluation.

The RECON III-B manufactured by Perry Oceanographics was selected as the most suitable ROV for the defined tasks. The field tests were conducted in February 1982. The vehicle performance was first assessed in a standard configuration. Then two foam lances and two racks of sampling devices were mounted on the open framework of the vehicle (Figure 27) and the performance characteristics were again evaluated. Additional tests were conducted to evaluate RECON's ability to maneuver the foam lances into simulated damage test target holes and retrieve chemical/water samples without introducing any significant self-contamination.

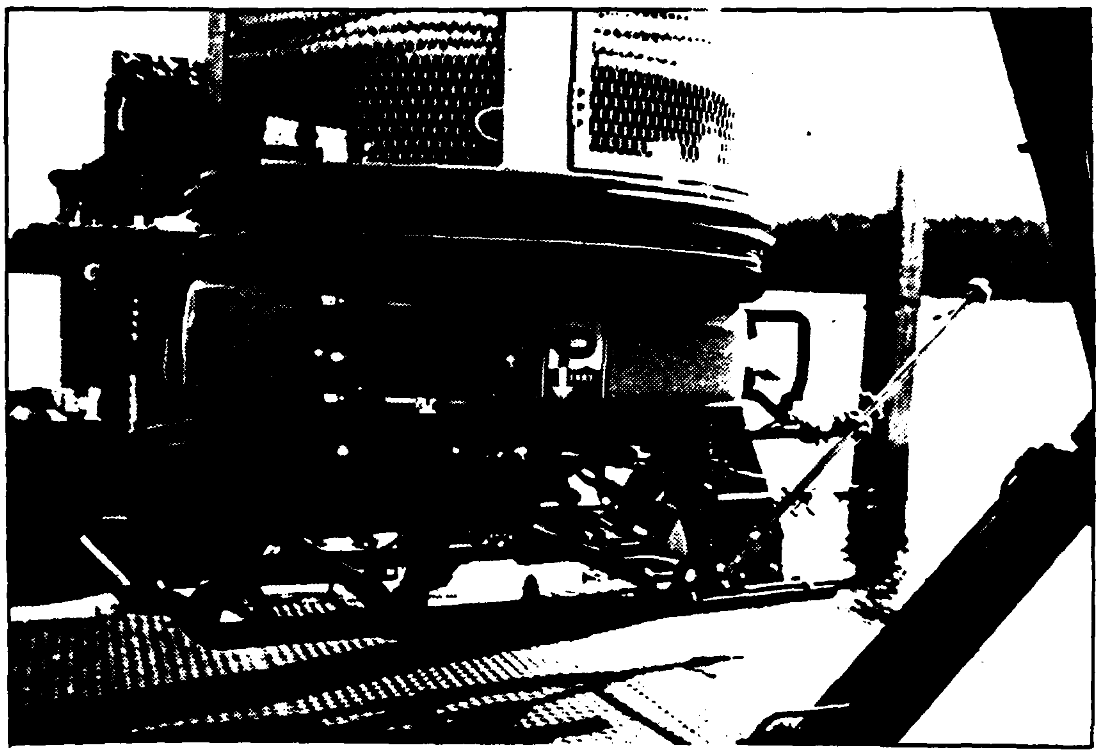


Figure 27. RECON Vehicle with Foam Lance and Sampling Devices Attached

The field test results showed that the RECON III-B was capable of performing the required inspection, sampling and plugging tasks under most conditions. Surface wave-induced surge hampered the plugging procedure due to a reduction in the vehicle's station keeping ability in near surface rough water conditions. The tests also showed that the configuration of the Coast Guard's foam plugging device should be modified to be acceptable for remote vehicle deployment. The contractor submitted an engineering report which included a hazardous chemical/vehicle material compatibility study. This study concluded that the RECON vehicle was acceptable for operation in hazardous chemical environments as defined by the study parameters. Vehicle maintenance procedures for this type of operation were also detailed.

Due to the significant costs of the RECON system (approximately $380K) and relatively infrequent requirements for this capability, it was recommended that this hardware be leased on an as-needed basis. The final report "Feasibility of Using RECON III-B as a Coast Guard Hazardous Chemical Spill Response Tool" (reference 10) was completed in March 1983.

5.0 SUMMARY

The Hazardous Chemical Discharge Prevention and Reduction project was one of six projects in the Coast Guard's Hazardous Chemical Discharge Amelioration Program. The overall program was aimed at investigating and developing equipment and methods for responding to hazardous chemical spills in the marine environment. For various reasons the majority of equipment and techniques developed by the Coast Guard prior to this program were directed primarily at oil spill response. This was one project in a significant effort by the Coast Guard to develop safe and effective methods for responding to hazardous chemical spills. The principal objective of the project reported here was to investigate and develop equipment and methods to prevent the discharge of hazardous chemicals from an endangered marine vessel, and to stop or reduce the discharge from a container which is already leaking. The project was implemented in three phases:

Phase I - Background Study
Phase II - Problem Definition
Phase III - Hardware Development

Phases I and II provided the foundation for the majority of the project work conducted under Phase III. The principal areas of concern established for investigation and hardware development were:

(a) Hazardous chemical offloading systems which included a pumping system and interim storage containers.

(b) Hazardous chemical plugging devices.

(c) Damage assessment and hardware delivery systems.

Offloading Systems: Study results in this work area identified modifications to the Coast Guard's existing ADAPTS pumping system increasing its ability to pump some corrosive chemicals. In addition, the all stainless

steel Framo TK-5 pump underwent test and evaluation. It was successfully operated using both the ADAPTS and VOPS prime movers. These tests provided the information for writing a procurement specification for a hazardous chemical pumping system.

As part of the offloading system, the Vapor Reduction Device was developed. The VRD is used to reduce the toxic vapor levels around a deck opening during the emergency offloading process.

Temporary containment devices are also part of the hazardous chemical offloading system. In the past the Coast Guard has procured DRACONES (Dunlop Ltd) Containers for temporary transfer of petroleum products at sea. A simple analysis was performed which determined that approximately 160 of the 400 liquid chemicals of concern could be carried in the existing DRACONES. A contract study identified several design alternatives for a portable storage container. However, the recommended development program was a high cost and high risk venture which was not pursued further. Additional work was done which resulted in the development of a prototype rigid storage container designed to be deployed from the Coast Guard's Fast Surface Delivery Sled. The container system was field tested with the FSD. The system was proven feasible, but the sled required modifications which would possibly interfere with other primary functions. Test results and participants' comments also indicated that the small capacity would severely limit the utility of this container system. Further development was not pursued.

Patching and Plugging Devices: This work area resulted in the development and handoff of several plugging devices. The Rockwell foam plugging system underwent some major design modifications to make it suitable for leak plugging underwater. A bulk loading system to support the foam lance was also designed and fabricated. Additional development work resulted in completion of the air/CO_2/water-filled bag, the Self-Contained Underwater Pumping System for "inflating" these bags, as well as the evacuated foam plug. Field tests conducted with Strike Team divers showed these plugging devices to be effective particularly in combinations of one or more of the various types. Temporary plugging effectiveness up to 90% was achieved even in the irregularly shaped test target holes.

A study contract was let to investigate the feasibility of plugging leaking chemical containers from the inside. The contractor identified a small number of systems with potential for development, however, it was noted that this would require a significant effort. Work in this area was terminated in favor of the external plugging approach.

Delivery and Damage Inspection Systems: This work resulted in the development of the Remote Damage Inspection System. RDIS consists of a high resolution video system and cage assembly allowing damage inspection of a tankship or barge from the deck of the stricken vessel. This system satisfied the Coast Guard's near-term inspection requirements. Concurrent work was conducted to develop a system capable of deploying the plugging devices mentioned above, chemical/water sampling apparatus, as well as a TV camera for remote damage inspection. The RECON III-B remotely operated vehicle system was field tested and shown to be capable of performing the required tasks.

High procurement cost and relatively infrequent use indicated the most cost effective approach would be to lease a system as needed.

5.1 Conclusions

The hardware developments resulting from the Hazardous Chemical Discharge and Prevention project have improved the Coast Guard's ability to carry out the marine environmental protection mission. Response personnel have been most enthusiastic about the hardware developed for vessel hull damage plugging and emergency offloading. The following data presented in the Pollution Information Reporting System Bulletin for 1979 and 1980 (reference 36) reflects an encouraging trend in the statistics for potential spills. These are spills to which the Coast Guard responded where the pollutant did not enter U.S. waters.

Table 4. Potential Spills of Hazardous Chemicals

Year	No. Incidents	Volume (Gallons)
1974	17	10,469,054
1975	11	18,443
1976	25	105,392
1977	36	3,548,775
1978	36	5,610,589
1979	62	15,973,944
1980	49	12,335,913

The positive trend in these statistics is most likely due to a multitude of reasons, including the improved response capabilities due to the Coast Guard's research and development efforts in this area. The Coast Guard's ability to deal with hazardous chemical spills should continue to improve as efforts in the other project areas within the Hazardous Chemical Discharge Amelioration Program are brought to completion.

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